Public Understanding of, and Attitudes toward, Scientific Research: What We Know and What We Need to Know

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Public Understanding of Science 2004 13: 273
DOI: 10.1177/0963662504044908

Public Understand. Sci. **13** (2004) 273–294

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Over the last four decades, a substantial body of national survey material has been collected in the US concerning the public understanding of science and technology. Using this body of research, this analysis outlines the major trends from 1957 to 1999 and discusses their implications for public understanding of, and attitudes toward, scientific research. The analysis found that although the rate of civic scientific literacy in the US is only now approaching 20 percent, there is a strong and continuing public belief in the value of scientific research for economic prosperity and for the quality of life. Even though there are some continuing reservations about the pace of change engendered by science and technology and the relationship between science and faith, the public consistently reconciles these differing perceptions in favor of science.

Introduction

There is broad consensus in the US and most industrial nations that it is important for citizens and leaders to be scientifically literate. Over the last two decades, a series of national studies sponsored by the National Science Foundation (NSF) have provided important baseline measures of the public understanding of science and technology. Miller (1983a, 1987a, 1987b, 1995, 1998a, 2000) has argued that a scientifically literate citizen needs to have: (1) a basic vocabulary of scientific terms and constructs; and (2) a general understanding of the nature of scientific inquiry. A series of US, European, Canadian, and Japanese studies have provided empirical measures of this definition of scientific literary. In broad terms, approximately 17 percent of US adults qualified as being scientifically literate by the end of the twentieth century and this level is equal to the levels estimated for Britain, France, Denmark, and the Netherlands, and better than all other countries, including Japan and the other members of the European Union not cited above (Miller et al., 1997; Miller and Pardo, 2000; Miller, 2000).

The proportion of US adults qualifying as being scientifically literate has doubled over the last two decades, but the current level is still problematic for a democratic society that values citizen understanding of major national policies and participation in the resolution of important policy disputes. Numerous studies have examined the factors associated with this pattern of growth in the level of scientific literacy in the US (Miller, 1983a, 1983b, 1987a, 1992, 1995, 2000, 2001) and need not be reviewed in detail at this point.

 ISSN 0963-6625 DOI: 10.1177/0963662504044908

There has been a growing sense in the scientific community that it is important for a larger proportion of Americans to understand the nature of scientific research, some of the conditions that encourage or discourage scientific and technological innovation in a society, and current issues associated with scientific research. The purpose of this report is to summarize what is presently known about the level of understanding of science and technology by the public generally and by the several relevant segments of the public.

What we know

This report will focus first on what is known currently about public understanding of, and attitudes toward, scientific research and technology development in the US and the primary factors associated with these outcomes. The report will include findings from other industrial nations when available and appropriate.

Understanding

Any analysis of the public understanding of scientific research should begin with a definitional discussion of both "understanding" and "scientific research."

"Understanding" is a broad term, ranging from an elementary idea of what something means (or how it works) to a deep professional understanding of a concept or construct in the full context of its field. The depth of understanding required for a citizen to be able to follow and participate in public policy discussions of a scientific or technological issue has been the subject of extensive debate in recent years. Shamos (1995) suggested a standard of understanding that appears to reflect his expectations for his undergraduate physics students, and he concludes that public understanding at that level is unattainable and unnecessary.

By contrast, Miller (1983a, 1986, 1987a, 1995, 1998a, 2000) has defined the level of understanding needed for scientific literacy to be sufficient to read and comprehend the Tuesday science section of *The New York Times*. It is assumed that science policy leaders and other policy leaders will have defined the general framework of a policy dispute and that the public discourse over the dispute can be conducted at a level comparable to the language and construct level of *The New York Times*, *The Wall Street Journal*, *Le Monde*, or comparable major papers and magazines in the other countries. Although different scholars have used different operational definitions of understanding (one dimensional versus two dimensional), there is broad agreement that *The New York Times*' level of understanding is more appropriate than the Shamos expectation of a sound conceptual understanding of the laws of thermodynamics (Miller, 1983a, 1987a, 1995, 1998a, 2000; Miller et al., 1997; Miller and Pardo, 2000; Durant et al., 1989, 1992).

In his original conceptualization of scientific literacy, Shen (1975) argued that literacy should be viewed as a series of separate measures—one for citizenship roles, one for consumer roles, and one for a more general level of cultural understanding. To a large extent, the work by Miller, Durant, and others has focused on the level of understanding required for effective citizenship. The conceptualization and measurement of the level of information needed for consumer decision-making is more concrete and often more specific. In general, no one has proposed a single scale that would incorporate consumer understanding that would cover the full range of science and technology. The National Academy of Engineering (NAE) has proposed a general measure of technological literacy at the conceptual level (NAE, 2002) but has not developed a questionnaire or an empirical scale based on actual survey data.

In a more segmented approach, Miller and Kimmel (2001) have defined a measure of biomedical literacy that is useful in understanding individual participation in public policy matters concerning biomedical science and biotechnology as well as individual personal health decisions. For example, an individual facing a personal decision on gene therapy and an individual seeking to understand the debate over the use of embryonic stem cells in medical research would need to understand the role of DNA, the meaning and functions of stem cells, and the potential use of stem cells in the treatment of selected medical conditions. In both cases, some understanding of the evolution of life on this planet and the intricate web of life that reaches from microbes to humans would enrich the level of understanding, but it may not be absolutely essential to make either a specific personal or policy decision.

The analysis that follows will focus on the development of understanding at all levels but will examine the patterns in terms of a model of citizen, patient, and consumer decision-making that depends on understanding science, medicine, and technology at *The New York Times* reading level.

The concept "scientific research," as used in this report, will include a full range of scientific activity from basic research to applied research, but it will not include manufacturing or the development of specific applications of science in the development of consumer goods and products. It is important to explore the level of understanding of scientific inquiry as performed by scientists, focusing heavily on the role of theory development, theory testing, experimentation, falsification, and related issues.

Working within these broad definitions, the scholarly work of the last several decades has produced some important insights into the understanding of scientific research among ordinary citizens and their leaders. In broad terms, it is useful to group this work into studies of the understanding of scientific study or inquiry, experimentation, probability, specific scientific constructs, and specific products or results from scientific research.

Understanding of the nature of scientific study and inquiry

The baseline study in this area was conducted in 1957 by the National Association of Science Writers (NASW) only a few months before the launch of Sputnik I. Researchers at the Survey Research Center at the University of Michigan interviewed a national sample of approximately 1,800 adults about their interest in science and technology, their understanding of it, and their primary sources of information about it (Davis, 1958).

In the 1957 NASW study, each respondent was asked:

> Some things are studied scientifically, some things are studied in other ways. From your point of view, what does it mean to study something scientifically?

Ten percent of the respondents indicated that scientific study meant using an experimental method or other rigorous study methods. Four percent emphasized that scientific study required an open-minded approach, skepticism, and suspended judgment. Approximately half of respondents said that scientific study meant thorough and careful analysis, but they could not be more specific (Davis, 1958).

This topic was not measured in any national sample of adults for another 20 years. In 1978, the NSF selected Jon Miller and Kenneth Prewitt to design a new approach to the measurement of the public understanding of, and attitudes toward, science and technology for use in the *Science and Engineering Indicators* report series by the National Science Board (NSB). In their original 1979 US study, Miller and Prewitt built on the 1957 NASW question set and introduced a two-stage approach to asking about understanding the nature of scientific inquiry (Miller et al., 1980). Each respondent was asked:

> Some things are studied scientifically; some things are studied in other ways. Would you say that you have a clear understanding of what it means to study something scientifically, a general sense of what it means, or no understanding of its meaning?

Respondents who reported that they had a clear understanding of the meaning of scientific study were then asked:

> From your point of view, what does it mean to study something scientifically? (Just in your own words)

Using a set of independent coders to review the responses to both the 1979 question and the earlier 1957 question, it is estimated that approximately 12 percent of US adults were able to provide a minimally acceptable explanation of the meaning of scientific study in 1957 and that 14 percent were able to provide a similar answer in 1979 (Miller, 1987a).

Looking at the pattern over the last four decades, the percentage of US adults with a minimal level of understanding of the meaning of scientific study has increased from 12 percent in 1957 to 21 percent in 1999[1] (see Figure 1). While this pattern shows some improvement in recent years, it is clear that four out of five Americans do not understand the concept of a scientific study sufficiently well to provide a short sentence or two of explanation. This is an important issue for the communication of the results of scientific research to the public.

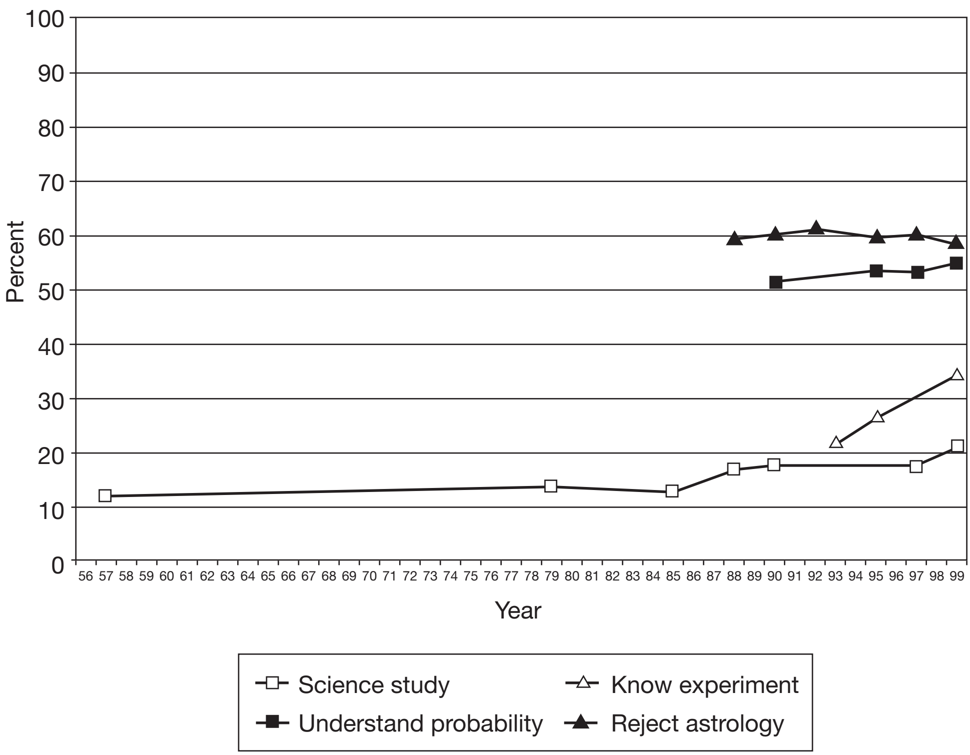

Figure 1. Public understanding of the nature of scientific inquiry, 1957–1999.

Understanding of experimentation

One of the most common terms used in explaining scientific research to the public is "experiment." Many press releases and reports to the public about new scientific or medical discoveries are often framed in terms of an experiment, and there has been a growing tendency for science journalists to report the number of individuals included in the treatment group and the control group.

In the context of the preceding discussion of the public understanding of the meaning of scientific study, how many US adults understand the nature of an experiment? One of the most common responses to the open-ended question about the meaning of scientific study was that a scientific study involved doing "an experiment." Often, this was the only response provided, and it was coded as correct, but Miller and others wanted an expanded measure of the meaning of experimentation. In a 1993 National Institutes of Health (NIH) Biomedical Literacy Study (Miller and Pifer, 1995) and in the *Science and Engineering Indicators* studies in 1995, 1997, and 1999, a new question concerning experimentation was used:

> Now, please think of this situation. Two scientists want to know if a certain drug is effective against high blood pressure. The first scientist wants to give the drug to 1000 people with high blood pressure and see how many experience lower blood pressure levels. The second scientist wants to give the drug to 500 people with high blood pressure, and not give the drug to another 500 people with high blood pressure, and see how many in both groups experience lower blood pressure levels. Which is the better way to test this drug? Why is it better to test the drug this way?

All respondents were asked the follow-up probe, regardless of which group they selected. This decision proved to be useful in assessing the level of understanding. In 1995, for example, 69 percent of respondents selected the two-group design, but the probe showed that a majority of this group—representing approximately 40 percent of the total population—indicated that they selected the two-group design so that if the drug "killed a lot of people," it would claim fewer victims because it would have been administered to fewer subjects. This is hardly the understanding of experimental logic that one would infer from the selection of the two-group design and illustrates one of the hazards of closed-ended questions. Approximately 12 percent of US adults selected the two-group design and were able to explain the logic of control groups. An additional 14 percent of Americans interviewed in the 1995 study selected the two-group design and provided a general rationale that included a "comparison" between the two groups, but lacked the language or logic of control groups. An additional one percent of respondents who selected the one-group option explained in the open-ended probe that they understood the logic of control groups, but could not ethically deny medicine to an ill person. This group was classified as understanding the nature of experimentation.

Looking at the results since 1993, the percentage of US adults who understand the basic idea of an experiment has increased from approximately 22 percent in 1993 to 35 percent in 1999 (see Figure 1). The slightly non-linear character of the 1995–1999 period serves to illustrate that there is a certain amount of error around each of these point estimates. It is likely that the general growth in the proportion of US adults who understand the concept of experimentation is the result of continuing increases in the proportion of the adult population who have had some college-level experience, including exposure to some college-level science courses (Miller, 1995; Miller et al., 1997) and to the growing emphasis on health and medical reporting in both print and broadcast journalism.

Understanding of probability

Probability is a basic concept that is important in understanding the nature and results of scientific research. With increasing frequency, the results of medical research and medical diagnoses are presented in probability terms. Probability underlies all inferential statistics, and the results of a wide array of scientific research are presented to the public—or segments of the public—in terms of the statistical reliability of the results.

Over the last decade, the *Science and Engineering Indicators* studies have included a set of items to measure the understanding of probability. A question posed a situation in which a doctor "tells a couple that their genetic makeup means that they've got a one-in-four chance of having a child with an inherited illness." Each respondent was asked to indicate whether each of four statements was a correct or incorrect interpretation of the meaning of one-in-four chances:

1. If they have only three children, none will have the illness.
2. If their first child has the illness, the next three will not.
3. Each of the couple's children has the same risk of suffering from the illness.
4. If their first three children are healthy, the fourth will have the illness.

Respondents were expected to select the third response as correct and the other three responses as incorrect, and approximately 57 percent of US adults gave those responses in 1988 (see Figure 1). Although there has been minor variation from year to year, the proportion of US adults demonstrating an understanding of probability has remained unchanged throughout the 1990s (NSB, 2000). This pattern suggests that exposure to an increasing volume of reports that include probability-based concepts does not increase the level of understanding by itself.

Rejection of astrology as scientific

In addition to understanding basic scientific constructs, it is important for citizens to recognize pseudoscientific constructs that seek to be recognized as scientific. Astrology is a good example. Since 1988, national samples of US adults were asked whether they though that astrology was "very scientific, sort of scientific, or not at all scientific." Throughout this period, approximately 60 percent of US adults recognized astrology as being not at all scientific (see Figure 1).

Understanding of specific scientific constructs

An individual's understanding of scientific research may depend, in part, on his or her understanding of a set of basic concepts or constructs. For example, a news story about the current debate over the use of embryonic stem cells may make little sense to an individual who has not heard about and does not understand DNA. Similarly, a news story about the storage of fuel rods from nuclear reactors may be difficult to understand for an individual who does not understand the nature of radiation or the concept of a half-life in the deterioration of radioactive materials. Because these basic constructs are rarely explained in current media in sufficient depth to foster basic understanding, most individuals must rely on previous formal and informal education for their basic inventory of scientific constructs.

This analysis will look at four basic constructs as representative of a much larger set of constructs that an individual might need to be able to read and understand a story in the Science Times section of the Tuesday *New York Times*—molecule, DNA, radiation, and the nature of the universe. Each of these constructs relates to current scientific research that is frequently reported in the general media. *Science for All Americans* (Rutherford and Ahlgren, 1990) may be seen as the most complete inventory of core constructs for a citizen wishing to understand science and technology policy issues. The four constructs selected represent both biological science and physical science.

Public understanding of the structure of matter is essential to following news about new scientific discoveries and debates about specific science and technology policy issues. The idea that a molecule is composed of two or more atoms is central to understanding a wide array of news and information about scientific research.

To assess the public understanding of the structure of matter, both the 1997 and 1999 *Science and Engineering Indicators* studies included a two-part question about each respondent's understanding of the term "molecule." Following the same approach described earlier, each respondent was asked whether he or she had a clear understanding of the meaning of a molecule, a general sense of the meaning of a molecule, or little understanding of this term. Respondents who reported having a clear understanding or a general sense of the meaning of a molecule were asked to explain the meaning of a molecule "in your own words." The resulting open-ended responses were coded by sets of independent coders and eventually classified as correct or incorrect. In 1997, 11 percent of US adults were able to provide a correct explanation of a molecule, and 13 percent were able to provide a correct explanation in 1999 (NSB, 2000).

This result is both surprising and troublesome. The term "molecule" has become a part of journalistic discourse on television and is often used in newspaper articles without additional explanation. An analysis of the open-ended responses indicated that many adults knew that molecules are very small but did not know whether atoms are composed of molecules or molecules are composed of atoms. Some individuals knew that a molecule is a basic building block and is very small but could not say anything else about it.

Public understanding of the nature of the universe is essential for citizens to make any sense of the pictures from the Hubble Space Telescope, the Chandra X-ray Observatory, and numerous other satellite platforms that portray parts of the universe. Setting aside their aesthetic value, these pictures are in essence public reports on some of the most fundamental research sponsored by the federal government. In this context, it is important to ask how much the public understands about the current scientific view of the universe.

In 1986, four years prior to the launch of the Hubble Space Telescope, Lightman and Miller (1989) asked a national sample of adults a series of questions about the universe and found a low level of basic astrophysical understanding. Fifty-five percent of adults responded correctly to the question "Would you say that the Sun is a planet, a star, or something else?" Only 24 percent of adults knew that the size of the universe is expanding.

Throughout the last decade, national studies found that about a third of US adults are aware of and accept the idea that "the universe began with a huge explosion" (NSB, 2000). A third of Americans overtly rejected this idea, and another third indicated that they did not know whether this construct was true or not. Some of the outright rejection reflects personal religious views. In recent years, many fundamentalist religious groups have rejected the idea of the Big Bang as being in conflict with biblical teaching, as they have done with evolution.

During the last 45 years, since the launch of Sputnik I in 1957, Americans have observed the development of human ability to send vehicles deep into space, to travel to the Moon and return, and to live and work in space stations. The federal government continues to spend slightly more than $16 billion each year for the space program. Apart from an understanding of the nature of the universe, it might be expected that four decades of exposure to news and information about space exploration would have produced some understanding of the solar system. Without a general understanding of the solar system, an individual would have a difficult time making sense of current research reports about space science or following policy debates about the desirability of a manned mission to Mars.

National studies find that only half of US adults know that the Earth rotates around the Sun once each year (NSB, 2000). One in five US adults say that the Sun rotates around the Earth, and 14 percent of US adults think that the Earth rotates around the Sun once each day (see Figure 2). A comparative study with Britain in 1988 found that only one-third of British adults understood that the Earth rotates around the Sun once each year, but the relative performance of US adults in this comparison should provide little comfort. The level of adult understanding of the solar system shows little change over the last decade, a period in which the NSF and other federal agencies have invested billions of dollars in the improvement of science education and in the improvement of informal science education for adults.

Public understanding of DNA is necessary for citizens in the twenty-first century. The last 50 years have witnessed a massive expansion of human understanding of biology. The double helix structure of DNA was first decoded in the 1950s, and the reconciled map of the human genome was released in April 2003, on the 50th anniversary of the publication of Watson and Crick's original article. During these five decades, human understanding of the nature of disease has advanced markedly, and there is some genetic-related news or information in the media almost every day.

The new genetic science is already involved in major public policy disputes, as reflected in the continuing policy debate over the use of embryonic stem cells for biomedical research (Chapman et al., 1999; National Research Council, 2001). Biomedical research—supported by an annual federal investment of more than $25 billion—is a major part of modern science and commands a substantial portion of news and media coverage about scientific research.

Knowing the basic concept of DNA is the key to understanding a wide array of current research. Studies of US adults over the last decade have found that about 40 percent have a minimally correct explanation of the meaning of DNA (NSB, 2000). In 1990, approximately 24 percent of US adults were able to provide an explanation of DNA that included its role in heredity (see Figure 2). By 1999, the percentage of adults giving a response that clearly identified DNA as being responsible for heredity increased to 29 percent.

This moderate pattern of growth in the public understanding of DNA reflects both the increasing centrality of DNA to understanding disease and health and the growing volume of high-quality media coverage of the issue. Numerous disease interest groups have recognized the role of DNA research in solving the problems associated with a specific disease and have provided a steady flow of relevant information through websites and traditional publications. The Juvenile Diabetes Foundation is a particularly good example (see www.jdf.org).

Public understanding of radiation, a common term in the political discourse of the latter part of the twentieth century, remains an important issue for citizens today. "Radiation" has become a common term in both speech and journalism. Regardless of whether an individual eventually favors or opposes the siting of a storage facility in Yucca Mountain, it is important for citizens trying to follow this policy debate to understand the basic information about the volume of material proposed for storage and the timescale for the continued radioactivity of the stored material.

Studies of US adults over the last decade have found that only one in 10 adults have a scientifically correct understanding of radiation (NSB, 2000). When asked in an open-ended question to explain the meaning of radiation, approximately 11 percent of US adults were able to provide an explanation that involved the emission of energy as particles or waves from a material or source (see Figure 2). Another 26 percent were able to name a source of radiation but not explain it. An additional 10 percent of adults were able to mention the

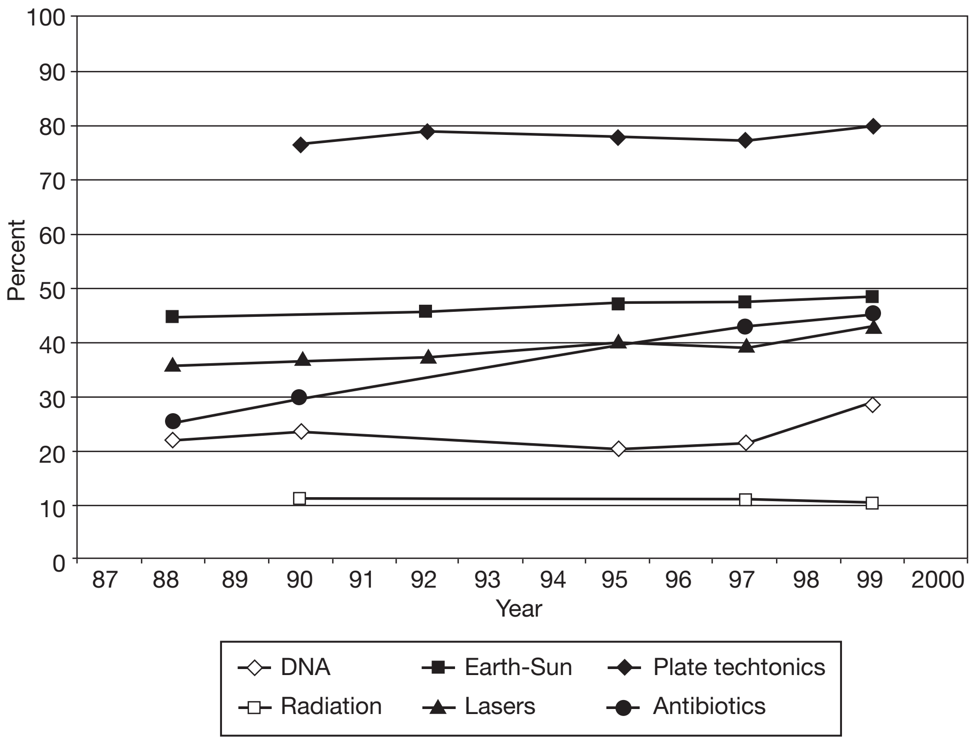

Figure 2. Public understanding of selected scientific constructs, 1988–1999.

effect of radiation but were unable to name a source or explain the meaning of radiation. These patterns have been largely unchanged since 1990.

Understanding of current scientific research or projects

Although the low level of construct understanding undoubtedly limits the understanding of scientific research by many individuals, it is important to examine the level of awareness and understanding of more specific scientific research projects or areas. Even if the level of understanding of the science involved is limited, an individual may understand the purposes of a particular scientific research project and have some understanding of the potential value of its results for his or her own life.

The range of current scientific research projects or areas is vast. For the purpose of this report, four specific examples have been selected to illustrate what we know and what we need to know about public understanding of current scientific research: the genetics of Alzheimer's disease; genetically modified food; Hubble's view of the universe; and research on global warming and climate change.

Alzheimer's disease is a major concern of aging adult populations worldwide. In recent years, there has been a steady stream of media coverage of possible genetic factors that might be responsible for Alzheimer's disease. There is solid evidence that the public is generally aware of this research, and some studies suggest that nearly 80 percent of adults would be willing to take a genetic test to determine if they were likely to develop Alzheimer's disease (Neumann et al., 2001). A comprehensive search of the existing literature found no studies of the level of public understanding of the genetic research concerning Alzheimer's disease.

Given the relatively low level of public understanding of the DNA construct itself, it would be surprising if a substantially higher proportion of adults understood the science involved in identifying the genetic factors that contribute to Alzheimer's disease or the genomic and proteomic solutions that are being studied. Nonetheless, it is this kind of research information that many adults are seeking, and the challenge for journalists and communicators will be to provide the needed information in a form and at a level that is comprehensible by a substantial proportion of adults.

Genetically modified foods have been a major topic of political discourse in Europe for more than a decade and are gradually becoming an issue for more Americans. Although possible applications of biotechnology to food production had been discussed throughout the 1980s, the first products reached the market in 1994 (Hoban, 1996a, 1996b). Several studies throughout the 1990s found that a majority of US adults reported that they had heard little or nothing about the use of biotechnology in food production (Hoban, 1996b; International Food Information Council (IFIC), 2000; Pew Initiative on Food and Biotechnology, 2001, 2002). The most recent survey, in September 2001, found that 56 percent of US adults continued to report that they had read or heard little or nothing at all about biotechnology (IFIC, 2001).

Although nearly 100 studies have measured consumer attitudes toward food biotechnology in the US, few have attempted to measure public understanding of the science of biotechnology generally or the research of plants and animals related to food production. In a 1997–1998 national study, Miller (1998b, 1998c) found some understanding of the basic constructs involved in food biotechnology but substantial confusion about other food-related constructs. On the fundamental issue of genes, 10 percent of US adults think that ordinary tomatoes do not contain genes and 45 percent do not know. While the 45 percent of US adults who rejected the statement was higher than adults in the European Union, this is a disappointing result. Only one-third of US adults understood that it is possible to transfer genes between plants and animals. Sixty-one percent of US adults knew that eating a genetically modified fruit would not modify the genes of the person eating the fruit.

Hubble's images of the universe rank among the most impressive in the history of human observations of nature. These images from the Hubble Space Telescope and other satellite platforms that measure X rays, gamma rays, and infra-red rays, are inherently challenging to Earth-centric views of life and creation, and must lead many individuals to think about cosmic questions. The limited research on the public understanding of the universe was described earlier. It is disappointing that there is no empirical record of the impact of these images on the thinking of citizens about the place of Earth in the scope of the universe.

Research on global warming and climate change is widely covered by the media and is a frequent component of political debate in the US. A substantial body of research demonstrates that most adults in the US believe that the Earth is experiencing the early stages of global warming and that these changes portend serious consequences for society (Krosnick and Visser, 1998; Harris Interactive, 2001; Program on International Policy Attitudes (PIPA), 2001). Kowalok (1993) provides an excellent introduction to the development of the global climate change issue, comparing it to, and differentiating it from, the acid rain issue and the ozone depletion issue.

Studying small numbers of adult volunteers, Bostrom et al. (1994) and Read (1994) found substantial confusion about the causes of global warming. This exploratory research found that many adults used local weather experiences to explain global climate changes and frequently confused the issue of stratospheric ozone depletion with global warming.

When asked directly about the role of carbon dioxide, approximately two-thirds of US adults agree that CO_2 is the major factor in the warming of the Earth's atmosphere (Harris Interactive, 2001; Krosnick and Visser, 1998; Wirthlin Worldwide, 1998). Krosnick and Visser (1998) found that 52 percent of adults agreed that global warming would cause the level of the oceans to rise, and 69 percent of adults agreed that weather would become more turbulent during the next 100 years because of global warming. The experience of Kempton (1997) and Bostrom (1994) with open-ended questions would suggest that some portion of these responses were agreements without substance.

Understanding of specific products or results from scientific research

The results of scientific research are often seen by the public in the form of products. It is important that individuals understand the linkage between the products that they use and the scientific research that led to these products. Three widely used products have been selected as illustrative of public linkage to scientific research and public understanding: antibiotics, lasers, and computers and the Internet.

Public misunderstanding of antibiotics continues to be a public health problem throughout the world. Antibiotics are one of the products of twentieth century science that most Americans encounter on a regular basis. The public embrace of antibiotics illustrates the public acceptance of new science without an understanding of its biologic basis. The widespread misuse of antibiotics has led to the development of many new strains of bacteria that are resistant to most antibiotics. National samples of US adults have been asked periodically over the last decade whether they think that antibiotics kill both bacteria and viruses (NSB, 2000). The percentage of adults who understood that antibiotics do not kill viruses increased from 26 percent in 1988 to 45 percent in 1999, the most significant growth among the constructs shown in Figure 2. Nonetheless, a majority of Americans still did not understand this basic biologic construct by the end of the century.

Public understanding of lasers illustrates the adoption of a physical science-based construct with a limited understanding of the science on which it is based. Lasers are used for cutting materials, doing eye surgery, storing data, and playing music. Lasers are a popular tool in movies, symbolized by the Star Wars light sabers, and were a prominent part of the public policy discussion that surrounded President Reagan's Strategic Defense Initiative in the 1980s. During the last decade, national samples of adults have been asked to agree or disagree with the statement "Lasers work by focusing sound waves" (NSB, 2000). The percentage of American adults who where able to correctly identify that statement as false increased only modestly over the last decade, from 36 percent in 1988 to 43 percent in 1999 (see Figure 2). By the end of the twentieth century, a majority of US adults still did not understand the composition of a laser.

Public understanding of computers and the Internet appears to have lagged behind the extraordinary acceptance and use of computers by US adults in the last decades of the twentieth century. In 1985, when personal computing was narrowly distributed, and in 1995, national samples of adults were asked in an open-ended format to explain the meaning of "computer software" (NSB, 1986, 1996). Responses that characterized software as instructions for a computer were coded as correct, and approximately 28 percent of US adults were able to provide a correct description in both 1985 and 1995.

In 1997 and 1999, national samples of adults were asked in an open-ended format to describe the Internet (NSB, 2000). In 1997, 13 percent of adults were able to describe the Internet as a worldwide network of computers that could communicate to each other. By

1999, 16 percent of adults were able to provide this level of definition. In both years, an additional 40 percent of adults were able to describe the Internet as an electronic connection to information or to a library, but did not include any reference to linkages among computers. In both 1997 and 1999, more than 45 percent of US adults could not offer even a general description of the Internet.

Attitudes toward scientific research

The preceding analyses have indicated that only a minority of US adults have a good understanding of the basic scientific constructs that underlie modern scientific research or a firm understanding of some of the major applications of ongoing scientific work. Does this low level of understanding indicate a lack of public appreciation of, or support for, scientific research among US adults? The answer is no. A substantial body of research from the end of World War II to the present indicates that an overwhelming majority of US adults are interested in science and technology, believe that it has contributed to our standard of living, and are willing to support it with government funding.

Salience of scientific research

Throughout the post-war years, Americans have reported a high level of interest in science and technology. In the first decade after World War II, newspapers reported regularly on the science and scientists who built the bomb that ended the war, the development of pesticides that would rid the world of insect pests, and antibiotics that would eliminate many common infections and illnesses. The discovery of a polio vaccine in the 1950s solidified the public's conviction that scientists could solve any problem. A landmark study of public interest in science and technology in 1957 only a few months before the launch of Sputnik I found a high level of interest in news stories about medicine, health, and science (Davis, 1958).

In national surveys of adults throughout the last two decades, a substantial proportion of Americans have reported a high level of interest in new scientific discoveries and new medical discoveries. For at least the last 15 years, approximately 70 percent of US adults have reported that they are very interested in new medical discoveries. The percentage of US adults with a high level of interest in new scientific discoveries has grown from 35 percent in 1979 to 45 percent in 1999. A higher percentage of adults with more years of formal education and with more exposure to college-level science courses expressed a high level of interest in new scientific discoveries throughout the last two decades, but a majority of adults who did not finish high school also reported a high level of interest in new scientific discoveries (NSB, 2000). By the end of the twentieth century, an interest in science and technology had become a part of US culture.

The evidence suggests that the salience of science to Americans is deeply held. Since 1988, national samples of US adults have been asked periodically to agree or disagree with the statement "it is not important for me to know about science in my daily life." Throughout the last decade, approximately 15 percent of US adults have agreed with this statement, but more than 80 percent of Americans have disagreed with the idea that science is not important in their daily lives (NSB, 2000).

Benefits of science and technology

For at least the last 40 years, more than 80 percent of US adults have held a positive view of the benefits of science and technology. In the 1957 NASW study, each respondent was asked whether the world was better off or worse off because of science, and 88 percent of US adults indicated that they thought that the world was better off due to science (see Figure

3). Forty years later, Miller asked the same question in the 1997 and the 1999 *Science and Engineering Indicators* studies and found that the same percentage of American adults still thought that the world was better off due to science (NSB, 2000).

During the same 40-year period, the percentage of US adults agreeing with the statement "science and technology are making our lives healthier, easier, and more comfortable" decreased from 94 percent in 1957 to 81 percent in 1979, and then gradually increased to 90 percent in 1999 (see Figure 3). Throughout this 40-year period, a substantial majority of adults in every age, gender, educational attainment, and occupational category agreed with this view (Davis, 1958; NSB, 2000).

The evidence indicates that Americans see science and technology as improving opportunities for their children. Since 1985, national samples of Americans have been asked periodically to agree or disagree with the statement "Because of science and technology, there will be more opportunities for the next generation." Three-quarters of US adults agreed with this statement in 1985, and more than 80 percent have agreed with this view throughout the 1990s (NSB, 2000).

Reservations and concerns about science and technology

Simultaneous with the perception of the benefits of science and technology, Americans have voiced some concerns about the impact of science and technology on their lives and on society. It is important to recognize that perceptions of benefits and risks are not two ends of the same continuum, but two separate dimensions that tend to be negatively correlated in the US (Miller et al., 1997; Miller and Pardo, 2000).

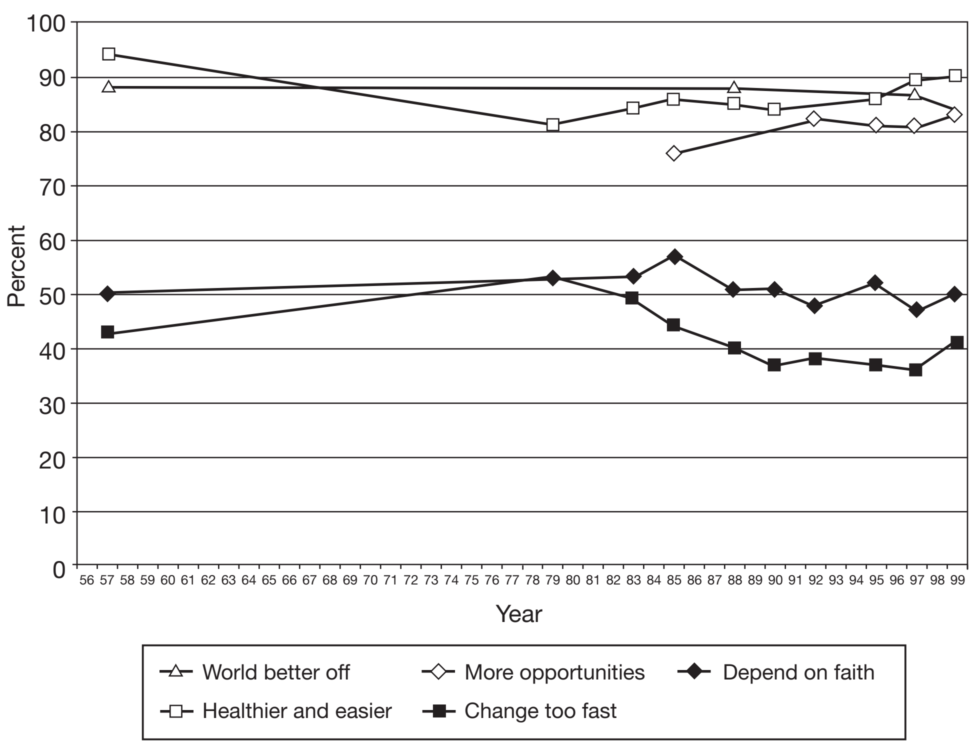

Figure 3. Attitudes toward science and technology, 1957–1999.

One of the most common concerns is that science and technology make life change too fast. Beginning in 1957, Americans have been asked periodically to agree or disagree that "Science makes our way of life change too fast." Since 1957, about 40 percent of US adults have agreed that science and technology make life change too fast (Davis, 1958; NSB, 2000). The percentage of Americans holding this view rose to more than 50 percent in 1979, but dropped below 40 percent for most of the 1990s (see Figure 3). By the end of the century, 41 percent of US adults thought that science and technology "change our lives too fast."

A second reservation concerns the impact of science and technology on traditional religious values and faith. Beginning in 1957, national samples of US adults have been asked periodically to agree or disagree with the statement "We depend too much on science and not enough on faith." Throughout this period, approximately half of US adults has agreed that there is too much dependence on science and not enough on faith (Davis, 1958; NSB, 2000). Although there have been fluctuations from year to year, the general pattern has been stable.

The reconciliation of benefits and reservations

A strong belief in the benefits of science and technology does not mean that individuals have no reservations about the impact of science and technology. Miller et al. (1997) investigated the relationship between public perceptions of the benefits of science and technology and their concerns about the impact of science and technology in Canada, the European Union, Japan, and the US. In all four societies, a set of factor analyses found that belief in the promise of science and technology and concern about negative consequences from science and technology were separate factors, or dimensions.

In the US and Canada, there was a moderately strong negative correlation between belief in the promise of science and technology and reservations about science and technology. These correlations of approximately –0.6 mean that individuals who hold a strong belief in the promise or benefits of science and technology were significantly less likely to hold strong reservations about science and technology, and vice versa. By contrast, the correlation between these two beliefs in the European Union was –0.11, meaning that many individuals in Europe who held a positive view of the promise of science and technology also held moderately strong (but slightly weaker) reservations about the impact of science and technology.

Recognizing that a positive view of the benefits of science and technology and an awareness of actual or potential risks are not mutually exclusive, a series of national studies over the last 20 years asked national samples of US adults whether "the benefits of scientific research have outweighed the harmful results" or whether "the harmful results of scientific research have outweighed its benefits?" During the last 20 years, the percentage of adults who concluded that the benefits of scientific research were greater than its harms increased from 70 percent in 1981 to 75 percent in 1999 (see Figure 4). By the end of the twentieth century, a substantial majority of adults in every age, gender, educational attainment, and occupational category expressed the view that the benefits of scientific research outweigh any current or potential harmful results (NSB, 2000).

Support for scientific research

Given the preceding set of attitudes, it is not surprising that a substantial majority of Americans support government spending for scientific research, including basic scientific research. Most citizens have little idea about the actual level of federal or governmental appropriations for any given purpose, including scientific research. It is important to

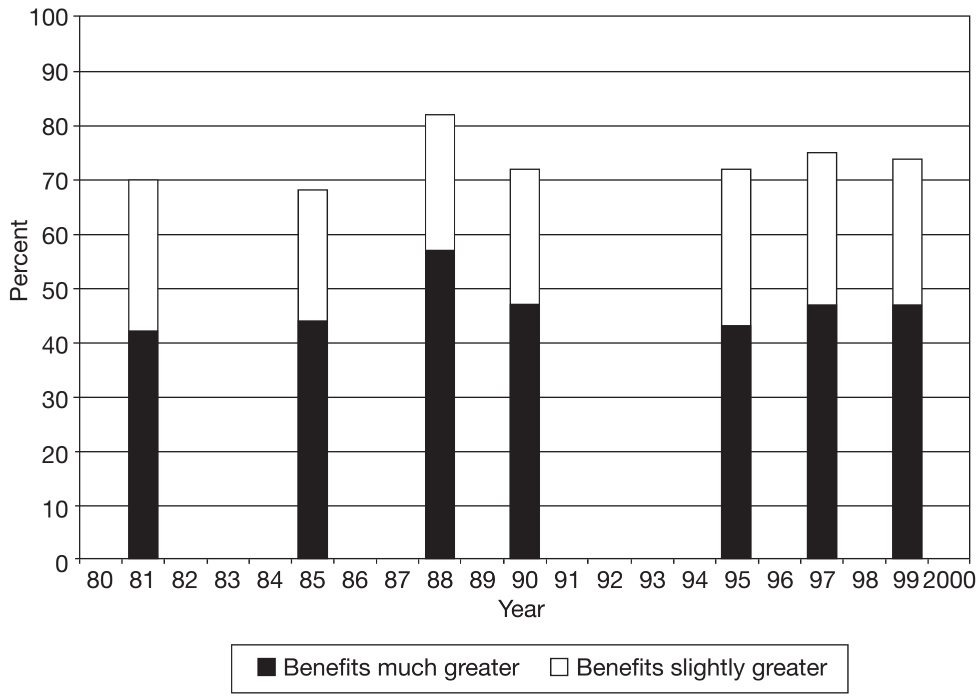

Figure 4. Public assessment of the benefits and harms of scientific research, 1981-1999.

recognize that for most individuals these judgments are not based on real or estimated expenditures, but reflect a general feeling that the government should be providing more support for some activities or less support for other activities.

Since 1981, national samples of US adults have been asked periodically to indicate whether the "government" is spending too little, too much, or about the right amount for the "conduct of scientific research." About one-third of US adults have reported that the government is spending too little for scientific research, and about 45 percent of adults have indicated that they think government spending for scientific research is about right. By the end of the twentieth century, only 14 percent of US adults thought that the government was spending too much on scientific research (NSB, 2000).

One of the long-standing concerns of the scientific community has been the fear that the public would support only applied scientific research focused on a particular disease or product and would not be willing to support basic scientific research. To assess the public's willingness to support basic scientific research, national samples of adults have been asked periodically since 1985 to agree or disagree with the statement "Even if it brings no immediate benefits, scientific research which advances the frontiers of knowledge is necessary and should be supported by the federal government." Approximately 80 percent of Americans have agreed with this statement throughout the last 15 years (NSB, 2000).

Factors associated with understanding scientific research

Why do some people know more about scientific research than others? What are the factors that predict acquisition, retention, and use of information about scientific research?

Although there is no single indicator of the understanding of scientific research per se, Miller's measure of civic scientific literacy includes all the constructs discussed above in regard to scientific research. A detailed discussion of the conceptualization and measurement of civic scientific literacy is provided in the refereed literature (Miller, 1998a). In practical terms, the level of concept vocabulary and process understanding required reflects the level of skill required to read most of the articles in the Tuesday science section of *The New York Times*, watch and understand most episodes of *Nova*, or read and understand many of the popular science books sold in bookstores today.

Using this measure, approximately 10 percent of US adults qualified as civic scientifically literate in the late 1980s and early 1990s, but this proportion increased to 17 percent in 1999 (see Figure 5). Since each percentage point in a national survey of adults aged 18 and older in the US represents approximately 2.0 million individuals, this result means that about 34 million Americans were civic scientifically literate by the end of the twentieth century. This rate of civic scientific literacy is higher than that found in Canada, the European Union, or Japan, using similar measures (Miller et al., 1997; Miller and Pardo, 2000).

To identify the factors associated with civic scientific literacy, a structural equation analysis[2] of the 1999 US data set was conducted (Jöreskog and Sörbom, 1993). The analytic model included each individual's age, gender, highest level of education, number of college science courses completed, presence or absence of minor children in the household, and level of use of informal science education resources. The total effect of each of these variables on civic scientific literacy is shown in Figure 6.

Despite a general expansion of educational access in the US in the last half of the twentieth century, both age and gender had a moderately strong influence on civic scientific literacy in 1999. Holding constant all the other factors in the model, women were slightly

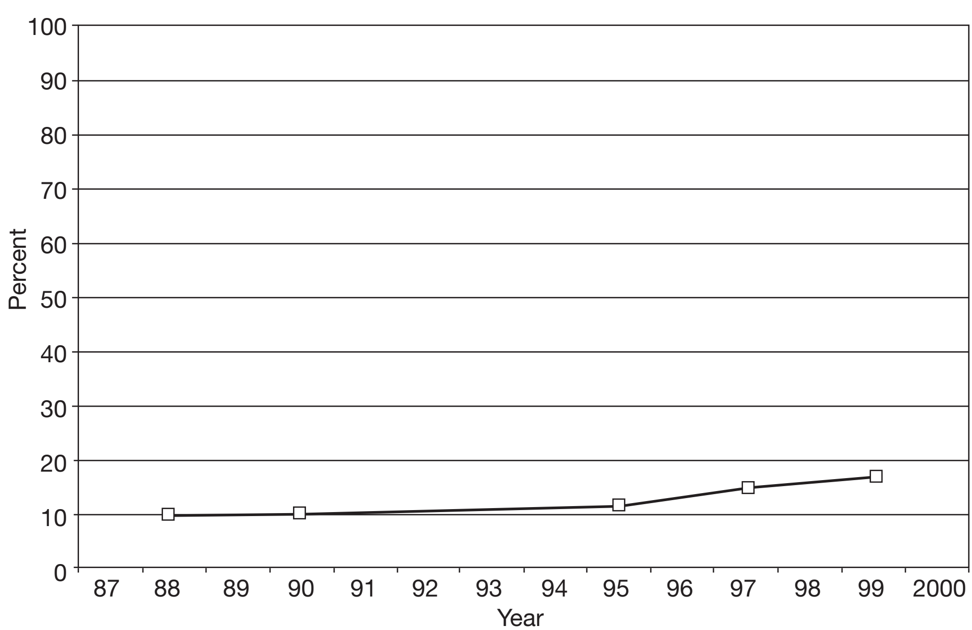

Figure 5. Percentage of American adults who are scientifically literate, 1988–1999.

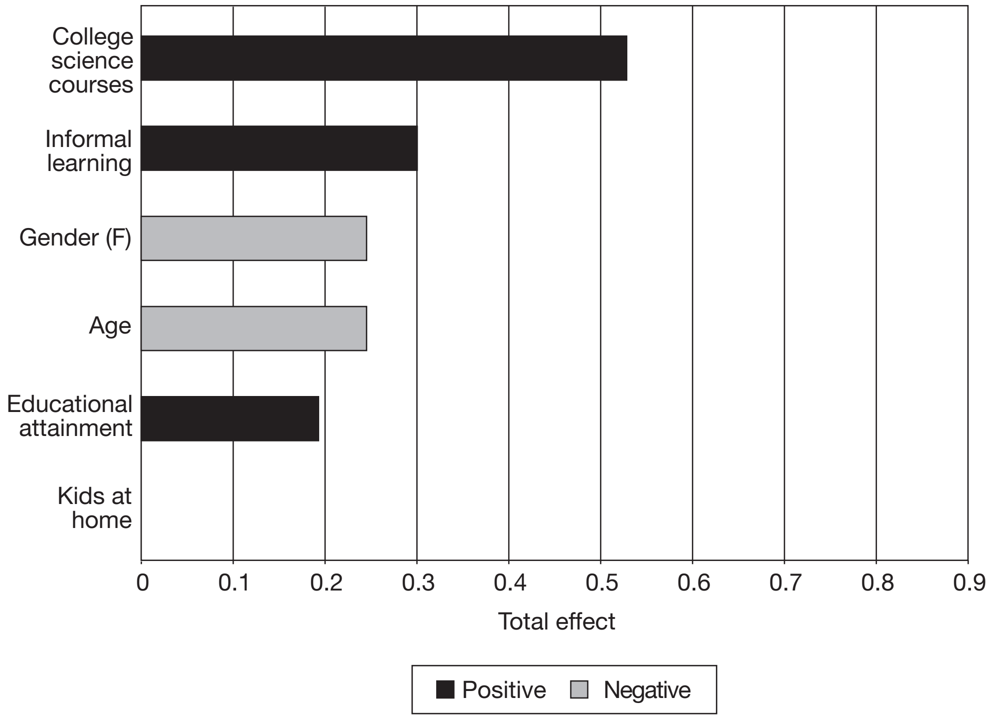

Figure 6. Total effect of selected variables on civic scientific literacy, 1999.

less likely to be scientifically literate than men (–0.24) and older adults were slightly less likely to be scientifically literate than younger adults (–0.24). Independent of age and gender, the level of educational attainment was positively related to civic scientific literacy (–0.19).

The number of college-level science courses taken is the strongest predictor of civic scientific literacy (0.53). The variable is a measure of the number of college-level science courses, including courses at both community colleges and four-year colleges and universities, but excluding graduate courses. The number of courses was divided into three levels: (1) no college-level science courses; (2) one, two, or three courses; and (3) four or more courses. Those individuals with one to three courses reflect the students who took college-level science courses as a part of a general education requirement rather than as a part of a major or a supplement to a major. The use of an integer measure would have given undue weight to majors and minimized the impact of general education science courses in the analysis.

The US is the only major nation in the world that requires general education courses for its university graduates. University graduates in Europe or Japan can earn a degree in the humanities or social sciences without taking any science course at the university level. In cross-national studies, a slightly higher proportion of US adults qualify as scientifically literate than do adults in the European Union or Japan, and comparative structural equation analyses of those data show that this exposure to college-level science courses accounts for the US performance (Miller et al., 1997; Miller and Pardo, 2000). Although some university science faculties view general education requirements with disdain, these analyses indicate that the courses promote civic scientific literacy among US adults despite the disappointing performance of US high school students in international testing (Schmidt et al., 1997).

The model also included a variable indicating whether there were any minor children living in the respondent's household. In this model, the net impact of having minor children in the home, also known as the "science fair" effect, was 0.02, indicating a miniscule effect on parents and children's scientific literacy (see Figure 6).

The analysis found that the use of informal science education resources was positively related to civic scientific literacy (0.30). The measure included each individual's use of science magazines, news magazines, science books, science museums, home computer, science websites, and the public library (Miller, 2001). The magnitude of the influence of informal education resource use—second to college-level science courses—indicates that the efforts of members of the scientific community to enhance the scientific literacy of non-scientists is having a positive effect.

What are the implications of this work for the public understanding of scientific research? First, it is clear that the general education requirement of at least a year of science courses continues to make a major contribution to the civic scientific literacy of citizens who are outside the scientific community. Previous studies have shown that civic scientific literacy is positively associated with support for basic scientific research and for the intellectual freedom needed for good science (Miller, 1995; Miller and Pardo, 2000). The value of these courses needs to be recognized, and they need to be made more effective in the years ahead.

Second, the accelerating pace of scientific development will place increasing demands on informal science educators—science writers, journalists, television and movie producers, and webmasters—and their institutions to keep Americans up to date about new scientific research and technological developments after the end of formal schooling. The relatively strong influence of informal science education resource use in the 1999 analysis indicates that the system is working, but it will need the help and leadership of more members of the scientific community to meet the accelerating demands of the twenty-first century.

Finally, it is clear that the best long-term strategy for increasing civic scientific literacy is to improve pre-collegiate education so that all students who graduate from college are scientifically literate. The fact that college-level science courses are currently able to compensate in part for inadequate middle school and high school science should be of little consolation to the scientific community. A slightly higher proportion of US adults might qualify as more scientifically literate than European or Japanese adults, but the truth is that no major industrial nation in the world today has a sufficient number of scientifically literate adults. No pride can be taken in a finding that four out of five Americans cannot read and understand the science section of *The New York Times*.

What we need to know

What do we need to know to improve the public understanding of scientific research? On the basis of the preceding analysis of the literature and the available data sets, three primary areas require substantially more attention in the next decade than they have received in recent years:

1. The central questions regarding adult learning about scientific research all involve defining and measuring *changes in adult knowledge and behaviors*, yet the cumulative weight of the literature provides limited evidence about changes in adult information seeking, retention, and use. The primary problem has not been the absence of interesting

theories or models. In the 1960s and 1970s, a solid literature on socialization and learning developed, fed in part by the first longitudinal studies of students and by extrapolations of socialization experiences to adult populations. Berger and Luckmann (1966) provided a life-cycle model of human learning and behavior, integrating constructs from linguistics and social psychology. Sternberg (1988a, 1988b, 1999; Sternberg et al., 2000) has provided an interesting theory of human information acquisition, retention, storage, recall, and use. The majority of the existing literature on adult learning about science and technology broadly, and about adult understanding of scientific research, is based on cross-sectional studies. There is a compelling need to invest in adult longitudinal studies that will map the dynamic of human information acquisition, retention, and use generally and in regard to science and technology.

2. In principle, improvements in science education and health education during the pre-collegiate years should provide a solid foundation for adult learning later in life. There is solid evidence that exposure to college-level science courses does make a significant impact, but it is not clear why there is so little impact from pre-collegiate science education on later adult behaviors and performance. Given the substantial and growing national investment in the improvement of science and mathematics education, it is important to examine this issue in a careful and systematic manner.
3. It is critically important to monitor the impact of the information technology revolution on the development of scientific literacy, biomedical literacy, and on the public understanding of scientific research. The tools for communication and learning are unparalleled in both quality and access and will undoubtedly have a substantial impact on adult information seeking and acquisition, but the nature and direction of this impact are not clear. It is tempting to try to draw a parallel with the invention of the printing press, the telephone, or television, but all comparisons fail in the scope of their impact and the compression of the time frame in which this impact is occurring.

Acknowledgements

The preparation of this report was supported by NSF grant ESI-0003029. The time series data from 1979 to the present included in this report were collected with support from NSF grants and contracts SRS-7816839, SRS-8105662, SRS-8517581, SRS-8807409, SRS-9002467, SRS-9217876, SRS-9732170, and SRS-9906416. All findings, conclusions, and opinions expressed are the responsibility of the author and do not necessarily express the views of the National Science Foundation, the National Science Board, or their staff.

Notes

1. Beginning in 1981, the *Science and Engineering Indicators* studies were conducted by telephone rather than in person, as had been done in 1957 and 1979. The same combination of a first question asking each respondent to assess his or her own understanding of the meaning of scientific study followed by an open-ended probe of the meaning of scientific study was employed in national studies conducted in 1981, 1983, 1985, 1988, 1990, 1992, 1995, 1997, and 1999. In these interviews, any respondent who reported that he or she had a clear understanding of the meaning of scientific study or a general sense of it was asked the follow-up probe (NSB, 2000; Miller, 1983b, 1987a, 1995, 1998a, 2001).
2. In general terms, a structural equation model is a set of regression equations that provide the best estimate for a set of relationships among several independent variables and one or more dependent variables. For all of the structural analyses presented in this report, the program LISREL was used, which allows the simultaneous examination of structural relationships and the modeling of measurement errors. For a more comprehensive discussion of structural equation models, see Hayduk (1987) and Jöreskog and Sörbom (1993). For a more detailed example of the use of this technique in the analysis of civic scientific literacy, see Miller et al. (1997).

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